PB85-116093

Improved Techniques for Removal of Sediments Contaminated with Hazardous Materials

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Prepared for

Municipal Environmental Research Lab.
Cincinnati, OH

Oct 84

U.S. Department of Commerce
National Technical Information Service
NTIS

PB85-116093

EPA-600/D-84-253
October 1984

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EPA Contract 68-03-3113

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REPRODUCED BY
NATIONAL TECHNICAL
INFORMATION SERVICE
U.S. DEPARTMENT OF COMMERCE
SPRINGFIELD, VA. 22161

TECHNICAL REPORT DATA
(Please read Instructions on the reverse before completing)

1. REPORT NO.	2.	3. RECIPIENT'S ACCESSION NO
EPA-600/D-84-253		PB85 116093

4. TITLE AND SUBTITLE	5. REPORT DATE
"Improved Techniques for Removal of Sediments Contaminated with Hazardous Materials"	October 1984
	6. PERFORMING ORGANIZATION CODE
7. AUTHOR(S)	8. PERFORMING ORGANIZATION REPORT NO.
R.S. Wetzel, JRB; A.N. Tafuri, EPA; J.R. Sinclair, CG	
9. PERFORMING ORGANIZATION NAME AND ADDRESS	10. PROGRAM ELEMENT NO.
JRB Associates 8400 Westpark Drive McLean, VA 22102	CBRD1A
	11. CONTRACT/GRANT NO.
	Contract No. 68-03-3113
12. SPONSORING AGENCY NAME AND ADDRESS	13. TYPE OF REPORT AND PERIOD COVERED
Municipal Environmental Research Lab - Cinn., OH Office of Research and Development U.S. Environmental Protection Agency Cincinnati, Ohio 45268	Conference Paper
	14. SPONSORING AGENCY CODE
	EPA/600/14

15. SUPPLEMENTARY NOTES

Anthony N. Tafuri (201) 321-6604

16. ABSTRACT

Realizing the need to improve the capabilities of response personnel in dealing with cleanup operations involving contaminated sediments, the U.S. Coast Guard and the U.S. Environmental Protection Agency have jointly funded a research project to: (a) identify, characterize, and classify chemicals that sink and are amenable to recovery by dredging and/or other techniques such as in-situ treatment; (b) review the state-of-the-art of contaminated sediment management technology to document and identify improved methodologies for handling and disposing of contaminated sediments; (c) implement pilot-scale studies on recommended modified approaches identified under the state-of-the-art work; and (d) perform field demonstrations of methods and equipment developed. The first two activities under this program have been completed and are the subject of this paper.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS	b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group

18. DISTRIBUTION STATEMENT	19. SECURITY CLASS (This Report)	21. NO. OF PAGES
Release to Public	Unclassified	13
	20. SECURITY CLASS (This page)	22. PRICE
	Unclassified	

EPA Form 2220-1 (9-73)

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IMPROVED TECHNIQUES FOR REMOVAL OF SEDIMENTS CONTAMINATED WITH HAZARDOUS MATERIALS

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Abstract

Removal of contaminated sediments by dredging poses numerous technical and economic problems. These problems include the availability of dredging equipment suited for removing contaminated sediments in an environmentally sound manner, the ability to accurately delineate the extent and depth of the contaminated sediments, the availability of techniques for managing contaminated dredged material (e.g., dewatering, transporting, disposal), and the need to improve efficiency and cost effectiveness of the dredging operations. Actual "hands-on" type data relating to these problems are minimal because there have been only a limited number of documented contaminated sediment dredging operations in the United States.

Realizing the need to improve the capabilities of response personnel in dealing with cleanup operations involving contaminated sediments, the U.S. Coast Guard and the U.S. Environmental Protection Agency (EPA) have jointly funded a research project to: (a) identify, characterize, and classify chemicals that sink in watercourses and are amenable to recovery by dredging and/or other techniques such as in-situ treatment; (b) review the state of the art of contaminated sediment management technology to document and identify improved methodologies for handling and disposing of contaminated sediments; (c) implement pilot-scale studies on recommended modified approaches identified under the state-of-the-art work; and (d) perform field demonstrations of methods and equipment developed.

The first two activities under this program have been completed and are the subject of this paper. The work was performed by JRB Associates under EPA Contract No. 68-03-3113, Task No. 14, and was jointly funded by EPA and the Coast Guard under an interagency agreement. The content of this paper does not necessarily reflect the views or policies of the EPA or the Coast Guard, nor does mention of trade names, commercial products, or organizations imply endorsement by the U.S. Government.

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Introduction

There are essentially three possible courses of action that can be taken to deal with sediments contaminated with hazardous materials:

- Take no action and allow the contaminated material to remain in place;
- Remove contaminants and sediments and treat, recover, and/or dispose;
- Isolate or treat contaminated sediments *in situ* using physical or chemical means.

The first option is often unacceptable because of the environmental and health threats posed. Environmentally safe and economical methods are needed to remove, isolate, or treat contaminated sediments. Removal of contaminated sediments by dredging has been performed at several sites in the U.S. and more extensively abroad. Isolation of sediments from the water column and *in situ* treatment, on the other hand, have received little attention in the U.S. and are not considered established techniques.

Maximizing the volume of sediments removed from a water body in a given amount of time has been the major focus of development of dredging equipment and practices in the U.S. until recent years when environmental impacts began receiving consideration. The spread of contaminants during dredging operations is linked to the resuspension of sediments, particularly clay-sized and organic particles, which are associated with the majority of contaminants. Conventional dredges are usually designed for maintenance of large harbors and other water bodies and are not specifically designed for removal of contaminated sediments in small watercourses. Modifications to existing equipment and operating methods are sometimes made to accommodate these situations. In addition, new specialized dredging equipment is being developed in the U.S. and abroad to specifically address reducing environmental impacts. Managing the large volume of dredge material also poses numerous problems. Current technology includes pumping and handling of material removed from contaminated areas; dewatering sediment; treating supernatants; and storing, treating, transporting and disposing of contaminated sediments.

Under the Federal Water Pollution Control Act (PL 92-500) and the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA or "Superfund"), the United States Coast Guard (Coast Guard) and the United States Environmental Protection Agency (EPA) are mandated to ensure safe cleanup of hazardous chemical discharges in waters in the United States, including bottom sediments which underlie the waters. In addition, the U.S. Army Corps of Engineers is charged with maintaining the navigability of commercial waterways by dredging sediments to maintain adequate channel depths. The Coast Guard and EPA are concerned primarily with removal of contaminants (which may be in contact with sediments), while the Corps is concerned primarily with removal of sediments (which may be in contact with contaminants).

Realizing the need to improve the capabilities of response personnel in dealing with cleanup operations involving contaminated sediments, the Coast Guard and EPA have jointly funded a research project to advance the state of the art with respect to problem characterization; sediment removal; dredged materials treatment, storage, and disposal; and other possible options (e.g., *in situ* treatment) to deal with the problem of contaminated sediments. Although the missions of the funding groups differ (i.e., the Coast Guard focuses on spills of chemicals on the Chemical Hazards Response Information System (CHRIS) list, while EPA is concerned with a wider range of chemicals associated with industrial discharges and hazardous waste contamination, as well as spills), the basic techniques utilized and the problems encountered in responding to cases of sediment contamination are similar for both groups.

Specific objectives of the project include: (a) identification, characterization, and classification of chemicals that sink and are amenable to recovery by dredging and/or other techniques such as *in situ* treatment, (b) state-of-the-art review of contaminated sediment management technology to document and identify improved methodologies for handling and disposing of contaminated sediments; (c) implementation of pilot-scale studies on recommended modified approaches identified under the state-of-the-art work; and (d) large-scale/field demonstrations of methods and equipment developed. The first two activities under this program have been completed and are the subject of this paper.

Identification, Characterization, and Classification of Hazardous Chemicals that Sink

Sinking chemicals, which are chemicals that are denser than water and relatively insoluble in water, present a serious potential threat to sediments underlying surface water bodies. If a sinking chemical is spilled and enters a surface water body, it tends to fall or flow to the bottom and, if liquid, tends to permeate the sediments. Once there, the properties of the spilled chemical determine its fate and potential hazards to people and to the environment.

The tendency of a chemical to sink in water can be predicted from its specific gravity (a measure of density relative to the density of water) and from its water solubility. The water solubility of a chemical is the maximum mass of the chemical that dissolves per unit mass of water and can be expressed in parts per million (ppm). The solubility thus represents the concentration of the chemical at saturation in water. In addition important properties for predicting environmental transport, fate, and impact include physical state, reactivity, toxicity, bio-accumulation potential, and aquatic persistence. Physical state and reactivity with water help determine the potential threat of the chemical in the sediments. Liquids flow more readily than solids and dissolve more rapidly if they are soluble. Chemicals that react exothermically (i.e., with liberation of heat, which speeds the reaction and dissolving) are likely to become rapidly dispersed, creating a water body contamination problem.

If the spilled chemical remains at the bottom, it can permeate the sediments and enter the food chain through ingestion by benthic organisms, or decompose slowly to form water soluble products, or slowly dissolve or become suspended in the water body, and produce toxic effects in aquatic and terrestrial flora and fauna. More seriously, the chemicals may produce toxic effects in humans who drink the water, eat the plants or animals, or come in contact with the water. Whether these events occur at all, and the extent to which they occur, is determined by the toxicity, bioaccumulation, and aquatic persistence of the spilled chemical. Therefore, the urgency of remediation in the event of a chemical spill to surface water is determined by the properties of the spilled chemical. Knowledge of these properties will also help in deciding what remedial actions are necessary and those most likely to be effective.

To assist on-scene coordinators in responding to spills of sinker chemicals, a data base was developed using chemicals from the CHRIS list and chemicals regulated under CERCLA. This data base expands on the 1978 report, "A Feasibility Study of Response Techniques for Discharges of Hazardous Chemicals that Sink," performed for the Coast Guard by the Corps of Engineers Waterways Experiment Station, by providing additional data on a larger number of chemicals. The resulting Hazardous Sinkers List contains 468 chemicals and the following information for each chemical (within the limitation of the availability of data):

- o CHRIS Code
- o Physical State
- o Specific Gravity
- o Water Solubility
- o Toxicity
- o Ignitibility
- o Reactivity
- o Bioaccumulation Potential
- o Aquatic Persistence
- o Recovery and Handling Hazards
- o Recommended Response Actions

The Hazardous Sinkers List provides information for answering such questions as "How serious is the spill?" and "What can be done to remedy the problem?"

Review of Contaminated Sediments Management Technology

The state of the art of contaminated sediments management technology was reviewed for the purpose of identifying technical areas where further research, development, testing, and/or evaluation is needed. The review was accomplished through an information search (literature, manufacturers, vendors, associations, interviews) and through research of incidents of planned and/or implemented contaminated sediments management with emphasis on remedial measures. The broad subject of contaminated sediments management was divided into the following functional categories for the purpose of the technology review:

- o Characterization and location of sediment contamination
- o Equipment and techniques for removing sediments
- o Dredged material management
- o <u>In situ</u> treatment methods.

This review revealed that many existing technologies, such as those from the construction, dredging, mining, wastewater treatment, spill-response, and hazardous waste management industries, are applicable to contaminated sediments management. The range of technologies that have been applied is best demonstrated through the investigation of actual incidents of contaminated sediments, some of which received actions resulting in total or partial contaminant removal or containment. The accompanying table provides a list of such incidents; their locations, settings, and contaminant(s) of concern; and the cleanup technologies that were both considered and utilized. In addition to conventional dredging technology, a variety of relatively unconventional methods were also employed, including: stream diversion followed by conventional methods, diver-assisted removal; backhoe and loader excavation; above-water and underwater hand-held dredges; and in-stream redeposition controls. Methods of dredged material management included the use of vacuum tanks and trucks, barges, impoundments, solids screening, and a variety of physical and chemical wastewater technologies for treatment of water removed along with contaminated sediments (supernatant water).

In addition to the technologies employed in the cleanup incidents, the information search further revealed a wide variety of other technologies that have potential applicability to cleanup of contaminated sediments. The equipment and techniques associated with these technologies were investigated. Those having high potential for wide application were identified and needs for further research, development, and/or demonstration were described. The findings and needs for advancing the technologies are summarized below.

-- Characterization and Location of Contaminated Sediments

Existing equipment and methods from the dredging industry ("sonar" for mapping depths and bottom countours) and from fields involving sampling of benthic organisms (various samplers for differing bottom conditions such as hardness, thickness of strata, grain size) are generally appropriate or adaptable for use in locating and characterizing contaminated sediments. Areas where additional research is needed include: further development of remote-sensing equipment for contaminant detection; further investigation of the mechanisms for contaminant dispersion transport and criteria for decision making; and filling remaining data gaps in the "Hazardous Sinkers List."

-- Equipment and Techniques for Sediment Removal

A variety of dredging and other sediment-removal equipment and techniques exist and appear appropriate for removing contaminated sediments. Considerable domestic and foreign research and development in this area are in progress. Research needs includes: making foreign equipment more readily available for demonstration and general use in the U.S.; development of improvements in safety equipment and procedures to eliminate and/or minimize the exposure of divers responding to spills; conducting side-by-side demonstrations of foreign and domestic dredges for evaluation of manufacturer-supplied performance data; and further development of a more rugged water-tight clamshell bucket.

SUMMARY OF INCIDENTS OF SEDIMENTS CONTAMINATION

Description	Cleanup Technologies*	Comments
DUWAMISH WATERWAY (Seattle, WA) PCB spill into tidal shipping channel tributary to Puget Sound	Pneuma dredge Air curtain Underwater hand-held dredge Settling tanks Settling impoundments Special landfill disposal On-site land disposal Sand filters Carbon adsorption	Cleanup conducted in two states: initial emergency response and planned final cleanup. Initial efforts did not achieve complete clean-up because of spread of contaminants by tidal action. Cleanup employed EPA transportable physical/chemical treatment system (sand filters and activated carbon) and the Italian-made Pneuma dredge (first application in U.S.), a low-turbidity pneumatic dredge.
GULF OUTLET OF MISSISSIPI RIVER (Shell Beach, LA) PCB spill into tidal shipping channel tributary to Gulf of Mexico	Airlift dredge Settling barges Special landfill disposal Coagulation/flocculation Carbon adsorption	Airlift dredge was fabricated from locally available materials. Divers were used to clear debris from the spill area. A Chromascope was used to locate bags of PCP.
HIRO HARBOR (Kure-Shi, Japan) Accumulation of nitrogen and ammonia in sediments of a coastal shipping port; attributed to long-term discharge of pulp waste	Cleanup dredge Settling barges Solidification Sanitary landfill disposal Coagulation/flocculation Carbon adsorption	Pilot-scale demonstration for future land reclamation project in the harbor. Early demonstration of the Cleanup dredge, a low-turbidity hydraulic dredge.
JAMES RIVER (Hopewell, VA) Accumulation of Kepone in sediments of a tidal shipping channel and commercial fishery tributary to Chesapeake Bay; attributed to long-term wastewater discharge	Cutterhead dredge Dustpan dredge Water column disposal Oozer dredge Settling impoundments Solidification On-site land disposal Carbon adsorption Photochemical degradation Ozonation Radiation Sorbents Capping	Feasibility studies followed by a comparative demonstration of the cutterhead and dustpan dredges (both hydraulic dredges) by Corps of Engineers. Full-scale cleanup is unlikely. Results of demonstration and monitoring of resulting turbidity provide information for evaluating needed maintenance dredging projects in the James River and other water bodies.
MILL RIVER (Fairfield, CT) Accumulation of lead in sediments of a small in-stream impoundment tributary to Long Island Sound; attributed to long-term industrial wastewater discharge	Portable hydraulic dredge Silt curtains Settling impoundments Filter press Solidification Special landfill disposal Sanitary landfill disposal Coagulation/flocculation Water column disposal Capping Fixation	Coagulating polymer used to promote settling of fine dredged solids. Sediment disposed at both hazardous waste and sanitary landfill, depending on lead concentration. Belt filter presses used to dewater sediments; mechanical problems caused by presence of debris (bricks, spikes) in sediment.

SUMMARY OF INCIDENTS OF SEDIMENTS CONTAMINATION
(CONTINUED)

Description	Cleanup Technologies*	Comments
NORTH FORK HOLSTON RIVER (Saltville, VA) Accumulation of mercury in sediments of a small, fast-flowing rural river in industrial area; tributary to Tennessee River; attributed to long-term leakage from nearby industry	Stream diversion Cofferdams Dragline dredging Loader dredging Screening solids On-site land disposal Capping	River flow was diverted using sand bag cofferdams; cofferdams were twice washed out by high river flows. Fine (1/4-inch) screens clogged readily, 1/2-inch screens used successfully. Screened material was 1/3 of total volume and contained 99 percent of recovered mercury. Exposed river bottom was capped with hydraulically applied concrete.
SOUTH BRANCH OF THE SHIAWASSEE RIVER (Howell, MI) Accumulation of PCBs in sediments of a small, shallow rural river; tributary to Lake Huron; attributed to long-term discharge of industrial cooling water	Dragline dredging Backhoe dredging Above-water hand-held dredge Amphibious dredge In-stream turbidity control Settling tanks Solids separation by settling Special landfill disposal Sanitary landfill disposal Sand filtration Carbon adsorption Stream diversion Cofferdams Scraper dredging Filter press Solidification	Majority of sediment removed by vacuuming system operated by workers wading in the shallow river. Removed sediments were separated into coarse and fine sizes by settling and filtering. Sediment disposed at both hazardous waste and sanitary landfills, depending on PCB concentrations. In-stream dams were used to contain resuspended contaminated sediment.
SOUTH RIVER AND SOUTH FORK SHENANDOAH RIVER (Waynesboro, VA) Accumulation of mercury in sediments of small and medium size rural rivers in Shenandoah Valley; tributary to Potomac River; attributed to long-term leaching of buried industrial waste	No action Stream diversion Cofferdams Amphibious dredge Special landfill disposal	Feasibility study resulting in "no action" as the most favorable alternative. Damage to river channel, costs, and projections of contaminant reduction by natural processes were major factors in the evaluation. Responsible industry will monitor sediment, water, and fish for up to 100 years.
STAMFORD AND NEW HAVEN HARBORS (Stamford and New Haven, CT) Accumulation of heavy metals in sediments of a commercial tidal shipping port tributary to Long Island Sound; sources of contaminants are not established	Clamshell dredging Capping	Contaminated sediments from Stamford Harbor were disposed in Long Island Sound and capped with clean sediments from New Haven Harbor. Some erosion of the cap was observed, attributed to currents resulting from a major storm. Evaluation of the effectiveness of the cap is in progress.

SUMMARY OF INCIDENTS OF SEDIMENTS CONTAMINATION
(CONTINUED)

Description	Cleanup Technologies*	Comments
UPPER HUDSON RIVER (Fort Edward, NY) Accumulation of PCBs in sediments of a medium size rural river, part of NY State Barge Canal System; attributed to long-term industrial wastewater discharge	No action Clamshell dredging Backhoe dredging Loader dredging Cutterhead dredging Settling impoundments Special landfill disposal On-site land disposal Coagulation/flocculation Sorbents Capping Chemical treatment Biological treatment Stabilization/containment	Feasibility study for cleanup of submerged and floodplain contaminated sediments. Capping and stabilization of floodplain sediments was recommended. Additional mapping of contamination and no immediate cleanup action were recommended for the submerged sediments.
WAUKEGAN HARBOR (Waukegan, IL) Accumulation of PCBs in sediments of a recreational boating harbor on west shore of Lake Michigan; attributed to long-term industrial wastewater discharge	No action Stream diversion Cofferdams Slurry wall Clamshell dredging Dragline dredging Backhoe dredging Scraper dredging Loader dredging Cutterhead dredging Dustpan dredging Hopper dredging Portable dredges Airlift dredging Pneuma dredging Oozer dredging Silt curtains Settling impoundments Settling barges Filter press On-site land disposal Coagulation/flocculation Sand filters Carbon adsorption Capping Fixation Chemical treatment Biological treatment	Exhaustive feasibility study resulting in recommendation of slurry wall containment, dredging and capping, fixation, and disposal in a chemical waste landfill. Various alternatives and subalternatives were developed from over 70 unit processes. Selection and implementation of cleanup actions are pending.

*Underscored technologies were implemented; remaining technologies were considered as alternatives.

-- Management of Dredged Material

Research needs for this area include: improved methods for removing water from dredged sediment and for separating fractions of sediments by grain size to reduce treatment and disposal costs; development of criteria for selecting appropriate treatment (including no treatment) and disposal methods; a manual for assisting decision makers (OSC's and other planners) in identifying and evaluating appropriate dredged material management technologies; and criteria to ensure that appropriate safeguards are provided to prevent secondary contamination (particularly of groundwater) following disposal.

-- In Situ Management Techniques

In situ management techniques are largely unproven and untried. Such methods hold promise as they offer benefits normally associated with "no action" (contaminants remain in place, minimizing chances of secondary contamination), while providing positive treatment or containment. Proposed research includes: developing novel techniques for removing small amounts of contaminated sediments or obtaining relatively undisturbed sediment samples; further study of the long-term stability and environmental effects of capping contaminated sediments with cover materials as a means of containment; further study of the long-term effectiveness and stability of disposing of contaminated sediments in underwater pits and trenches; investigation of the effectiveness and improved design and construction techniques for underwater barriers and diversion structures; and increased U.S. demonstration projects for in situ fixation techniques (e.g., injection of contaminated sediments with sealants or grouts).

-- Other Findings

Several findings and research needs involve more than one category of contaminated sediments management or are not applicable to any of the above categories. These needs include: the development of a manual of practice to aid decision makers in selecting technologies and planning and implementing cleanup in a thorough, systematic manner; and a study of the process for evaluating and considering the "no action" alternative, including data development and evaluation for use in both spill responses and feasibility studies for chronic problems.

The preceding identified needs were evaluated in terms of their potential for advancing the state of the art, avoidance of overlap with other ongoing research programs, and the time and resource limitations of this project. A discussion of continuing activities for this project follows.

Ongoing Activities

Three activities were selected to fulfill the remaining objectives of this project.

-- Investigation of Improved Methods for Selectively Separating Dredged Solids by Level of Contamination

Since a major portion of the contaminated dredged material management problem is associated with the volume of material that must be handled, costs can be minimized by isolating contaminated material and handling and disposing only that portion of the dredged material as "hazardous". The separation of solids by level of contamination appears to be possible by the tendency of contaminants to adsorb onto fine-grained sediments such as clays and organic material. Off-the-shelf equipment is limited in applications involving separation of contaminated sediments. The examination of cases where existing solids separation equipment has been employed indicates that development of equipment designed specifically for separation of dredged sediments by grain size would contribute significantly to the state of the art.

-- Preparation of a Manual of Practice for Responding to Contaminated Sediments Problems

A variety of approaches has been employed in selecting sediment cleanup methods, ranging from consideration of relatively few conventional alternatives to exhaustive examination of numerous proven and unproven technologies. Further, in only a few cases investigated in this study was "no action" considered as an alternative on par with "action" alternatives. It is clear that parties that may be responding to contaminated sediments problems have not had ready access to the full body of information that is available. A collection of existing information, geared toward a practical decision maker's approach to screening and selecting the most appropriate rapid response actions, would help ensure that available alternatives are not overlooked and that appropriate alternatives are evaluated in a logical framework.

-- Investigation of Ground Freezing Technology for Sampling and Removing Contaminated Sediments

Ground freezing has been used successfully to provide a temporary barrier to groundwater movement and temporary structural stability in the construction of dams and tunnels. It has recently come into consideration as a potential technique for containing and facilitating the removal of contaminants in sediments and groundwater. The process would involve placing refrigeration probes in the sediments at close intervals and cooling them from a portable refrigeration unit. Ice crystals would spread and form a wall of frozen sediment. The frozen contaminated sediment could then be lifted out with little disturbance to the remaining uncontaminated sediment, or it could be maintained in a frozen state until dredging or in situ treatment methods could be implemented. Current ground freezing methods are very slow and costly. They can freeze only a small zone about 1.5 feet in diameter and have high energy requirements. These limitations may make the use of ground freezing cost-effective only for removing small volumes of contaminated sediments or for collecting sediment samples. However, ground freezing technology has sufficient promise to merit further research to determine its feasibility and cost-effectiveness.